Hands-on Learning in Multiple Courses in Electrical and Computer Engineering

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Abstract

It has been reported that persistence rate of engineering students is relatively low. Several new pedagogical paradigms have been proposed to improve engineering education, such as the use of "hands-on" tools to change the learning style in the engineering classroom to more engaging teaching pedagogies. An approach that is being used to engage and retain electrical and computer engineering students is the Analog Discovery board (ADB). The paper describes the hands-on learning experiences of students who used the ADB in multiple courses. The paper discusses (i) the various laboratory experiments and class projects performed by the students, (ii) the knowledge and skills learnt by the students and (iii) the lessons learnt by the instructors while introducing ADB into freshman and junior level courses in the electrical and computer engineering. Preliminary data indicate that students are benefiting from the use of the ADB. Students report increases in their interest in subject content, motivation to learn, and confidence in their ability to learn.

1. Introduction

It has been reported that persistence rate of engineering students is relatively low. One of the reasons given by students for the low retention rate is the use of teaching methods that are not suitable for current populations of students who learn and acquire new knowledge quite differently from those of earlier generations, and students finding learning environments that are not engaging or motivating to them [1]. It has also been reported that retention rates can be improved through multiple strategies that include making curriculum changes, moving practical engineering laboratories earlier into the curriculum, integrating projects into classes, and other class enhancements [2].

Several new pedagogical paradigms have been proposed to improve engineering education, such as the use of hands-on tools to change the learning style in engineering classrooms to more engaging teaching pedagogies. Hands-on learning has proven to be an effective approach for improving retention by making learning experiences more engaging and motivating for students [3, 4, 5]. There are benefits of having portable hands-on learning equipment. Among the benefits are improved student engagement [6, 7, 8], and improved student learning [9]. In addition, the usage of portable equipment allows the hands-on activities to be adaptable to traditional lecture courses [4, 10, 11], lab settings [5], and homework/project activities [4].

Several portable hands-on learning equipment tools are available, such as Analog Discovery [12], MyDaq [13], Lab-in-a-Box [14, 15], Tessal [16], and mobile studio [7]. A portable equipment device that is being used to engage and inspire electrical and computer engineering students at Prairie View A&M University is the Analog Discovery Board (ADB). The paper will discuss (i) the laboratory experiments and class projects performed by the students in multiple courses, (ii) the knowledge and skills learnt by the students, and (iii) recommendations for other institutions that want to introduce the ADB into multiple courses in the electrical and computer engineering curricula.

2. Experimental Centric Pedagogy in HBCUs

Prairie View A&M University (PVAMU) is one of the Historic Black College and University (HBCU) in the nation. The Department of Electrical and Computer Engineering at PVAMU is one of the thirteen electrical/computer engineering programs at HBCUs that is using portable hands-on equipment to engage and inspire students. All thirteen electrical/computer engineering departments are using the Analog Discovery board (ADB) to provide experimental centric pedagogy to their students [17, 18, 19]. The board communicates to a computer through a USB interface. The operating software, WaveForms, can be downloaded free from Digilent website [12]. The operating software, WaveForms, provides all instrument functions and measurement results. The virtual instruments include a two-channel voltmeter, a two-channel oscilloscope, a two-channel waveform generator, a 16 channel logic analyzer, and two-fixed (+/- 5 V) dc power supplies, a network analyzer and a spectrum analyzer. The virtual instruments are equivalent to more expensive desktop instruments when the board is connected to a laptop computer through its USB port. The ADB is low-cost and portable device (about the size of playing cards).

3. Usage of ADB in Multiple Courses

3.1 Courses

In the Department of Electrical and Computer Engineering at Prairie View A&M University, the ADB is used in three courses: (i) ELEG 1021 Introduction to Electrical and Computer Engineering Lab, (ii) ELEG 3013 Network Theory II, and (iii) ELEG 3043 Electronics I. ELEG 1021 is a laboratory course, and ADB is used in the laboratory. However, ELEG 3013 and ELEG 3043 are lecture courses, and projects employing ADB are integrated into the lecture courses. All the three courses, mentioned above, are required courses for students with majors in either Electrical Engineering or Computer Engineering.

3.2 Freshman-Level Course

ELEG 1021 Introduction to Electrical and Computer Engineering Laboratory is a first year course. In ELEG 1021, the first year students perform twelve experiments from the Electrical Engineering Practicum [18], which is a cloud-based book with experiments that uses the Analog Discovery board and electronic parts kit to facilitate hands-on learning and self-exploration by the students. The typical experiments that were performed in the ELEG 1021 course are shown in Table 1and the experiments were described in the paper by the authors [20].

The ELEG 1021 course builds the laboratory skills of the students, and also allows the students to explore and experiment in the areas of (i) circuit analysis, and (ii) electronics. In the area of basic circuit analysis the students learn: (i) Ohm's Law, (ii) voltage divider rule, (iii) current divider rule, (iv) charging and discharge of a capacitor of RC circuit, and (v) resonant RLC circuit.

In the ELEG 1021 course, students are introduced to basic electronics devices and circuits such as: (i) semiconductor diodes and LEDs, (ii) half-wave rectification, (iii) Op Amp inverting and non-inverting amplifiers, (iv) envelope detection circuit. The students also experiment with electronic sensors such as: (i) TMP01 Thermal Sensor, (ii) ADXL237 Accelerometer, (iii) GT0950RP3 Speaker and ADMP504 Microphone.

With regard to the laboratory skills mastered in the class, the students are able to : (i) read resistor values by using resistor color code, (ii) build electrical and electronic circuits using breadboard, (iii) use virtual instruments, such as arbitrary waveform generator, oscilloscope, power supply, voltmeter, network analyzer, and (iv) obtain Bode plots by using Network Analyzer.

Table 1: Experiments Performed in ELEG 1021 Using ADB

#	**Laboratory Topics**
1	Introduction to Electrical Engineering, Lab Instruments, Procedures, Personal Test Lab
2	Power Supplies and Electrical Power
3	Signal Generators and Waveforms
4	Resistors and Ohm's Law
5	Diodes and Rectification
6	Capacitors and Time Constants
7	Inductors and Resonance
8	Thermal Sensors and Temperature
9	Accelerometers and Tilt Sensing
10	Microphones and Sound Sensing
11	Radio Frequencies and Amplitude Modulation
12	Amplifiers and Sound Amplification

3.3 Junior-Level Courses

ELEG 3013 Network Theory II is a junior level course that is normally taught during the fall semester. In the ELEG 3013 course, the students perform two projects in the lab with the ADB. The projects are integrated into the lecture class. The two projects are: (i) RLC resonant circuit, and (ii) Fourier series expansion of square and triangular waveforms. For the RLC circuits, the students use the Network Analyzer of the ADB to obtain the Bode plot of a RLC resonant circuit. Fig. 1 shows the RLC resonant circuits, and Fig. 2 shows the Bode plot obtained from an RLC circuit through the use of the Network Analyzer of the ADB. In addition to the coverage of the Fourier series in class, the students go to the laboratory during the class period to use the ADB to obtain the frequency content of square and triangular waveforms. The Fourier series expansion of a square waveform with peak value of A, frequency of f_0 and average value of zero is given as:

$$g(x) = \frac{4\mathrm{A}}{\pi}\sum_{n=1}^{\infty}\frac{1}{(2\mathrm{n}-1)}(\sin[(2\mathrm{n}-1)2\pi \mathrm{f}_0 \mathrm{t}]) \quad (1)$$

In addition to laboratory projects integrated into the lecture class, design projects are assigned to students wherein they use the ADB to assist them in the practical implementation of their designs. The students are allowed to take home the ADB to assist them in completing the design projects. Some of the completed design projects include design of bandpass filters, band-reject filter, low-pass and high-pass filters.

ELEG 3043 Electronics I is a junior level course that is normally taught during the spring semester. In the ELEG 3013 course, the students perform two projects in the lab with the ADB. The projects are integrated into the lecture class. The two projects are (i) operational amplifier applications, and (ii) diode rectification. In the operational amplifier applications project, the students build and test non-inverting amplifiers, active lowpass filters and adder circuits. The adder circuit is used to add the signals shown in Eq. (2). The two signals in Eq. (2) are similar to first two terms of Eq. (1). The waveform obtained from the adder circuit is shown in Figure 3. It can be seen that Fig. 3 is a quasi-square waveform.

$$f(x) = B_1 \sin(2\pi f_1 t) + B_2 \sin(6\pi f_1 t) \quad (2)$$

where $B_1 = 300$ mV, $B_2 = 100$ mV, and $f_1 = 2$ KHz.

Whereas, a project involving signal decomposition was performed in the ELEG 3013 Network Theory II course through the use of the ADB Spectrum Analyzer, waveform synthesis using an adder circuit was done in the ELEG 3043 Electronics I class. The two projects deepened the students' understanding of Fourier series expansion.

In the diode applications project, the students build the bridge rectifier shown in Figure 4. Various capacitors are connected across the resistor RL, and the ripple voltage is obtained by using the oscilloscope of the ADB. The measured ripple voltages are compared to theoretically calculated values. In addition, diodes D1 and D2 are replaced by LEDs, and the frequency of the source is reduced to 10 Hz. The students observed that the two LEDs alternatively turned on and off. The dynamics of the LEDs assisted the students to have a deeper understanding of the operation of the bridge rectifier circuit.

3.4 Multiple Exposure to Hands-on-Learning

Table 2 shows knowledge and skills exposed to students in the three courses. Through multiple exposure to hands-on learning the students are able to master laboratory skills, such as bread-boarding, troubleshooting, and the use of electrical components and electronic devices. In addition, the students became knowledgeable in the use of Network Analyzer and Spectrum Analyzer, equipment that are not commonly used by undergraduate students. Furthermore, the laboratory projects that were integrated in the lecture courses deepened the students' understanding of frequency response, Fourier series expansion, operational amplifiers and diode rectifiers. Furthermore, their mastery of the use of portable equipment and their enhanced laboratory skills will inspire the students to explore engineering concepts with ADB in future.

Table 2: Multiple Exposures to Hands-on Learning from Courses

Knowledge and Skills	ELEG 1021	ELEG 3013	ELEG 3043
Teaches lab skills such as bread-boarding and troubleshooting	yes	yes	yes
Uses ADB oscilloscopes and signal generators	yes	yes	yes
Uses ADB Network Analyzer for Bode Plot	yes	yes	yes
Uses ADB Spectrum Analyzer	no	yes	no
Laboratory projects are integrated into lecture course	no	yes	yes

4. Assessment Results

All students taking the courses completed evaluation surveys to provide the data for feedback and analysis on the effectiveness of the experimental centric pedagogy as well as usage of the ADBs. At the beginning of the semester, students completed the HBCU Pre-Survey on Experimental Centric Pedagogy. At the end of the semester, students completed the HBCU Post-Survey on Experimental Centric Pedagogy which asks the same set of questions as the pre-survey from the perspective of having completing the actual course. The post-survey instrument is shown in Appendix A. For the ELEG 1021 course, the researchers present post-survey results for the following semesters: (i) spring 2015, (ii) fall 2015, and (iii) spring 2016. Thirteen students completed the post-survey during the spring 2015 semester, 43 students completed the post-survey at the end of the fall 2015 semester and 18 students completed the post-survey at the end of the spring 2016 semester. A total of 74 students responded to the survey across the three semesters.

In addition, the students who took the ELEG 3013 (Network Theory II) and ELEG 3043 (Electronics I) classes completed surveys. The survey results are available for the following semesters: (i) fall 2014 (ELEG 3013 class with 38 students), (ii) spring 2015 (ELEG 3043 class with 30 students), (iii) fall 2015 (ELEG 3013 class with 30 students) and (iv) spring 2016 (ELEG 3043 class with 33 students). Table 3 shows the average results for the three courses.

Table 3 Perceived Changes with the Use of ADB in the Freshman and Junior Junior Level Courses

#	Perceived Changes	ELEG 1021 (%*)	ELEG 3013 (%**)	ELEG 3043 (%**)
1	Use of ADB was relevant to my academic area	81	84	92
2	Use of ADB motivated me to learn the content	81	82	83
3	My knowledge has increased as a result of Use	84	88	89
4	Use of ADB suited my learning needs	89	72	86

***** Number represents percentage of participants who responded, "strongly Agree" or "Agree" in post-survey. A total of 74 students in the ELEG 1021 classes who responded to the post-survey was across the semesters mentioned above.

****** Number represents percentage of participants who responded, "Strongly Agree"/ "Agree" in post-survey. n=71 for ELEG 3013 students, and n =63 for ELEG 3043 students.

From Table 3, it can be seen the students perceived that the use of the portable hands-on hardware was relevant to their academic area (81% for ELEG 1021, 84% for ELEG 3013 and 92% for ELEG 3043 and that the ADB motivated them to learn the course content (81% for ELEG 1021, 82% for ELEG 3013 and 83% for ELEG 3043). In addition, it is interesting to note that the knowledge of the students increased as the result of use of the ADB (84% for ELEG 1021, 88% for ELEG 3013 and 89% for ELEG 3043). Furthermore, a high percentage of students indicated that the use of the ADB was suited to their learning needs (89% for ELEG 1021, 72% for ELEG 3013 and 86% for ELEG 3043), Similar results have been obtained by thirteen institutions that used the ADB in a collaborative project [17, 18, 19].

5. Recommendations for Other Institutions

During the first time the ELEG 1021 course was taught with ADB, the students did not appreciate the power and capabilities of the low cost portable equipment, the ADB. The students were not aware of the existence of desktop laboratory equipment, such bench oscilloscopes, power supplies, signal generators, voltmeters and Network Analyzers. During the subsequent course offerings of ELEG 1021, the first year students were sent to electronic laboratory to observe the desktop laboratory equipment in the laboratory. The students appreciated how small portable equipment can perform functions similar to those of several desktop equipment that cost several thousands of dollars.

Since the first year students in the ELEG 1021 course are learning bread-boarding, troubleshooting, basic electronics and circuit analysis, it is important to make the class as small as possible to provide adequate attention to the students in the laboratory. If the class is large, several laboratory assistants, skilled with the use of ADB, are strongly recommended.

For the third year courses, since the projects are integrated into the lecture class, it is important to perform the laboratory projects very close to the time the topics underlying the projects have been discussed in class. In addition, since laboratory projects are performed during a regular class period of about 90 minutes, the instructor can save the students some time by making all the components and equipment for a particular project easily available to the students before the start of the laboratory projects.

6. Conclusions

The hand-held mobile technology, ADB, is being used to engage freshman and junior electrical and computer engineering students. Through multiple exposure to hands-on learning, the students are able achieve mastery with the use of the ADB, master laboratory skills, and understand deeply several topics covered in circuit analysis and electronics. In addition, the students became knowledgeable in the use of Network Analyzer and Spectrum Analyzer, equipment that are not commonly used by undergraduate students. Survey results indicate that students are benefiting from the use of the ADB. A high percentage of students indicated that the use of the ADB was suited to their learning needs, and that the ADB motivated them to learn the course content. In addition, the knowledge of the students increased as the result of use of the ADB.

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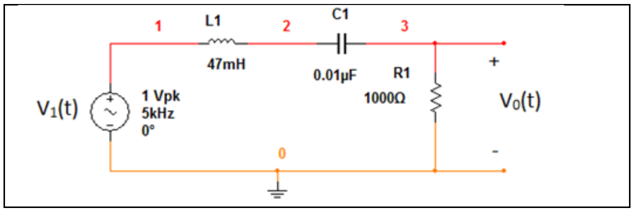

Fig. 1 RLC Circuit

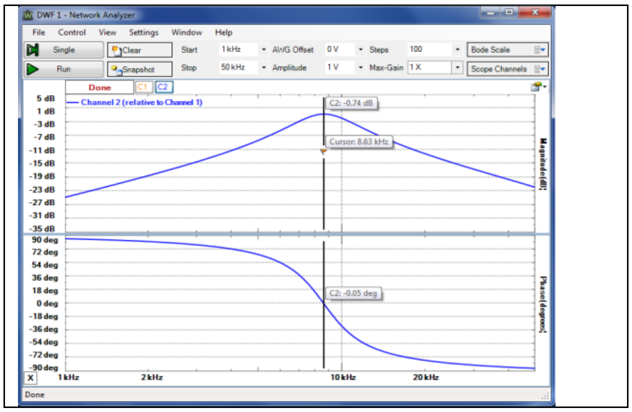

Fig. 2 Bode Plot of RLC Circuit Obtained using Network Analyzer of ADB

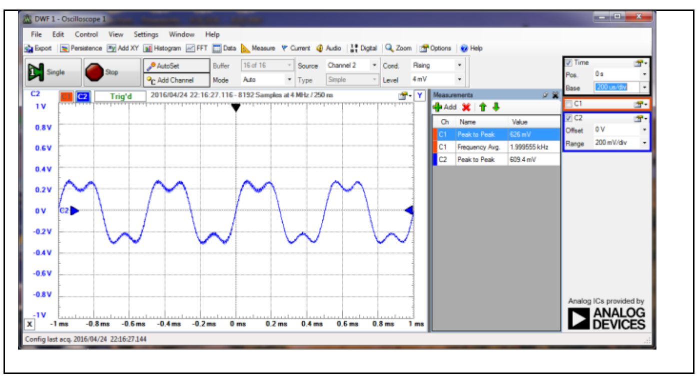

Fig. 3 A Quasi-square wave obtained from Adding two sinusoidal signals

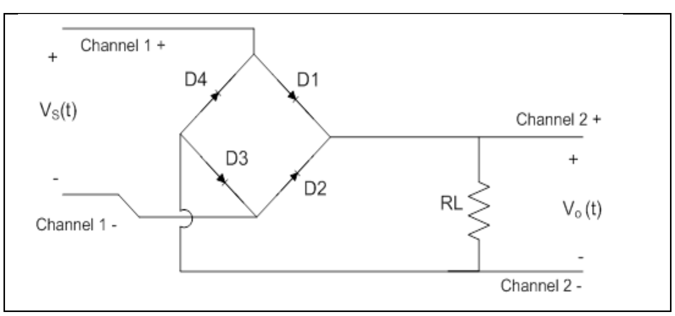

Fig. 4 Bridge Rectifier Circuit

Appendix A HBCU Post-Survey

HBCU Post-Survey

As part of efforts to evaluate *Experimental Centric Based Engineering Curriculum for HBCUs*, the Evaluation Consortium at the University at Albany/SUNY is collecting information from student participants. This information may be used to provide formative feedback to project staff, to document grant activities for the funder, and to aid in dissemination and knowledge development activities. Please read each of the following questions and provide the answer that reflects your status or opinion. Your participation is voluntary; your responses are strictly confidential and will not be released in any way that allows an individual to be identified. Only aggregate data will be presented in any reports. If you have any questions, please feel free to contact the Evaluation Consortium at the University at Albany/SUNY (518 442-5027 eval@albany.edu) or the University at Albany's Office of Regulatory Research Compliance (518 442-9050 orrc@albany.edu). *Thank you for your participation.*

Institution____________ **Course**______________________ **Semester**________________ **Date:**____________

First Letter of Your Mother's First Name:__________ **First Letter of Your Mother's Maiden Name:**__________

Last Two Numbers of Student ID #:_____________

About You. Check/Complete all that apply:

Student Status: Undergraduate: 1st year____ 2nd year____ 3rd year____ 4th year____ 5th year___
Graduate: 1st year____ 2nd year____ 3rd year____ 4th year____

Gender: Male____ Female____ **Age:**__________

Ethnicity: American Indian/Alaskan Native____ Asian____ Black/ African American____ Hispanic/Latino____
Multiracial____ Pacific Islander____ White ____

Is English your first language? Yes____ No____

Major:______________________________ **Minor**:______________________________

Experience.
If applicable, please indicate the ways in which you have had experience with the following materials/techniques using the scale below:

0= "Never" 1= "1-2 times" 2= "3-5 times" 3= "6-9 times" 4= "10+ times"

	Location/Setting			Method of Use		
Materials/Techniques	**In class**	**In lab**	**As homework**	**Instructor demo**	**Cooperatively**	**Independently**
Traditional Instruments (e.g., Oscilloscope, Function Generator…)						
Mobile Learning Platform (e.g., Mobile Studio, Analog Discovery, myDAQ)						
Circuit Building (e.g., Protoboards/ Breadboards…)						
Microprocessor Programming						
Online Video Lectures						

Engineering Knowledge. *As you think about this course and your current status, indicate your perceptions of: (a) the importance of the following skills and (b) how well prepared you are with regard to each of the skills.*
Please circle the descriptor which best describes (a) ***importance*** *AND (b) the extent of* ***preparation*** *received in the skill area, using the scales below:*

***Importance*: 1=Very Important 2=Important 3=Not So Important 4=Not At All Important**
***Preparation*: 1=Very Prepared 2=Prepared 3=Not So Prepared 4=Not At All Prepared**

Statement	Importance				Preparation			
1. Ability to apply scientific knowledge to engineering tasks.	1	2	3	4	1	2	3	4
2. Ability to design experiments.	1	2	3	4	1	2	3	4
3. Ability to interpret data.	1	2	3	4	1	2	3	4
4. Ability to design a system, component or process to meet the desired needs.	1	2	3	4	1	2	3	4
5. Ability to function effectively on multi-disciplinary team.	1	2	3	4	1	2	3	4
6. Ability to communicate effectively as a public speaker.	1	2	3	4	1	2	3	4
7. Knowledge of contemporary issues.	1	2	3	4	1	2	3	4

Appendix A HBCU Post-Survey (Continued)

Use of Portable Hands-on Hardware. *Please indicate your level of agreement for each of the statements regarding the use of portable hands-on hardware. Please, circle the number which best reflects your thoughts, using the following scale:*

1 = Strongly Agree 2 = Agree 3 = Slightly Agree 4 = Slightly Disagree 5 = Disagree 6 = Strongly Disagree

	Agree					Disagree
Format and Setting During Portable hands-on hardware Use						
1. Use was relevant to my academic area.	1	2	3	4	5	6
2. My knowledge has increased as a result of use.	1	2	3	4	5	6
3. My confidence in the content area has increased because use.	1	2	3	4	5	6
4. Using the Portable hands-on hardware motivated me to learn the content.	1	2	3	4	5	6
5. The Portable hands-on hardware provided opportunities for students to practice content.	1	2	3	4	5	6
6. The use of the Portable hands-on hardware reflected course content.	1	2	3	4	5	6
7. The use of the Portable hands-on hardware reflected real practice.	1	2	3	4	5	6
8. The time allotted for Portable hands-on hardware use was adequate.	1	2	3	4	5	6
9. The use of Portable hands-on hardware suited my learning needs.	1	2	3	4	5	6
10. The hands-on Portable hands-on hardware is important in my preparation as an engineer.	1	2	3	4	5	6
Supplementary Instructional Materials						
1. Handouts necessary for Portable hands-on hardware use were provided.	1	2	3	4	5	6
2. The visual aids (e.g. diagrams) used with Portable hands-on hardware were clear and helpful.	1	2	3	4	5	6
3. Instructions on Portable hands-on hardware use were relevant.	1	2	3	4	5	6
4. Instructions on Portable hands-on hardware use were helpful.	1	2	3	4	5	6

Effects of the Integration of Portable Hands-on Hardware. *Please rate the following statements according to what you believe use of portable hands-on hardware does for you. Use the following scale:*

1 = Strongly Agree 2 = Agree 3 = Slightly Agree 4 = Slightly Disagree 5 = Disagree 6 = Strongly Disagree

	Agree					Disagree
Using the Portable hands-on hardware helped me to:						
1. Develop confidence in content area.	1	2	3	4	5	6
2. Think about problems in graphical/pictorial or practical ways.	1	2	3	4	5	6
3. Apply course content to new problems.	1	2	3	4	5	6
4. Recall course content.	1	2	3	4	5	6
5. Develop interest in the content area.	1	2	3	4	5	6
6. Work collaboratively with fellow students.	1	2	3	4	5	6
7. Develop attitudes of self-direction and self-responsibility.	1	2	3	4	5	6
8. Develop different ways of solving problems.	1	2	3	4	5	6
9. Develop skills in problem solving in the content area.	1	2	3	4	5	6
10. Transfer knowledge/skills to problems outside the course.	1	2	3	4	5	6
11. Become motivated to learn course content.	1	2	3	4	5	6
12. Improve grades.	1	2	3	4	5	6
13. Confidently complete lab assignments.	1	2	3	4	5	6
14. Learn how AC and DC circuits are used in practical applications.	1	2	3	4	5	6

Overall, I believe the increased use of portable hands-on hardware in experiments for this course helped me learn more. (Please circle one)

Strongly Agree Agree Neutral Disagree Strongly Disagree

Overall, I believe the use of portable hands-on hardware experiments in this course enhanced my professional abilities. (Please circle one)

Strongly Agree Agree Neutral Disagree Strongly Disagree

Please indicate your level of confidence in engineering after participating in the course. (Please circle one)

Low Confidence High Confidence

1 2 3 4 5 6 7 8 9 10

1. Provide an example of how the use of the Portable hands-on hardware in this course benefitted you.

2. What would you change in the use of the Portable hands-on hardware in this course?

Thank you for your participation!